

(19) World Intellectual Property
Organization
International Bureau



(43) International Publication Date
21 October 2004 (21.10.2004)

PCT

(10) International Publication Number
WO 2004/090516 A1

(51) International Patent Classification⁷: **G01N 21/64**,
21/95, G01R 31/265

(21) International Application Number:
PCT/GB2004/001521

(22) International Filing Date: 8 April 2004 (08.04.2004)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
0308182.5 9 April 2003 (09.04.2003) GB

(71) Applicant (for all designated States except US): AOTI
OPERATING COMPANY, INC. [US/US]; 131 NW
Hawthorne Avenue, Suite 207, Bend, OR 97701 (US).

(72) Inventor; and

(75) Inventor/Applicant (for US only): HIGGS, Victor
[GB/GB]; 222 Maylands Avenue, Hemel Hempstead,
Hertfordshire HP2 7DF (GB).

(74) Agent: NOVAGRAAF PATENTS LIMITED; The Cres-
cent, 54 Blossom Street, York YO24 1AP (GB).

(81) Designated States (unless otherwise indicated, for every
kind of national protection available): AE, AG, AL, AM,
AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN,
CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI,
GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE,
KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD,
MG, MK, MN, MW, MX, MZ, NA, NI, NO, NZ, OM, PG,
PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SY, TJ, TM,
TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM,
ZW.

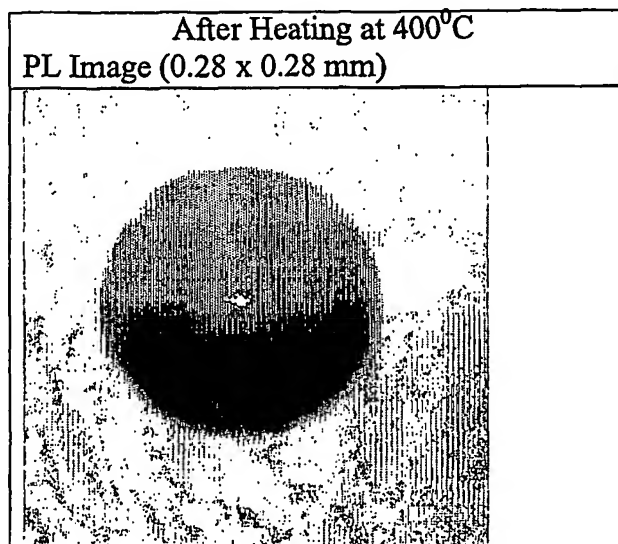
(84) Designated States (unless otherwise indicated, for every
kind of regional protection available): ARIPO (BW, GH,
GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW),
Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), Euro-
pean (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR,
GB, GR, HU, IE, IT, LU, MC, NL, PL, PT, RO, SE, SI, SK,
TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW,
ML, MR, NE, SN, TD, TG).

Published:

— with international search report

For two-letter codes and other abbreviations, refer to the "Guid-
ance Notes on Codes and Abbreviations" appearing at the begin-
ning of each regular issue of the PCT Gazette.

(54) Title: DETECTION METHOD AND APPARATUS METAL PARTICULATES ON SEMICONDUCTORS



(57) Abstract: A method of detecting surface
particulate defects, and especially metal particulates, in
semiconductors such as silicon, to characterise defects
likely to have an effect on the electrical activity of such
semiconductor materials, comprises exposing the surface
of the semiconductor structure in the vicinity of a surface
particulate to at least one high-intensity beam of light
and collecting and processing the photoluminescence
response; and using the result to identify unacceptable
contamination levels resulting from diffusion of
contaminant from particulate into semiconductor
structure. Optionally, the semiconductor is annealed
and photoluminescence responses collected before and
after annealing to identify contaminant diffusion rates.
Apparatus for the same is also described.

WO 2004/090516 A1

PCT

RECEIVED

20 JUL 2004

INTERNATIONAL SEARCH REPORT

WIPO

PCT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference P3159 WO ORD	FOR FURTHER ACTION see Form PCT/ISA/220 as well as, where applicable, item 5 below.	
International application No. PCT/GB2004/001521	International filing date (day/month/year) 08/04/2004	(Earliest) Priority Date (day/month/year) 09/04/2003
Applicant AOTI OPERATING COMPANY, INC.		

This International Search Report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This International Search Report consists of a total of 5 sheets.

☒ It is also accompanied by a copy of each prior art document cited in this report.

1. Basis of the report

- a. With regard to the **language**, the international search was carried out on the basis of the international application in the language in which it was filed, unless otherwise indicated under this item.

☐ The international search was carried out on the basis of a translation of the international application furnished to this Authority (Rule 23.1(b)).

- b. ☐ With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, see Box No. I.

2. ☐ **Certain claims were found unsearchable** (See Box II).

3. ☐ **Unity of invention is lacking** (see Box III).

4. With regard to the title,

☐ the text is approved as submitted by the applicant.

☒ the text has been established by this Authority to read as follows:

DETECTION METHOD AND APPARATUS METAL PARTICULATES ON SEMICONDUCTORS

5. With regard to the abstract,

☒ the text is approved as submitted by the applicant.

☐ the text has been established, according to Rule 38.2(b), by this Authority as it appears in Box No. IV. The applicant may, within one month from the date of mailing of this international search report, submit comments to this Authority.

6. With regards to the drawings,

- a. the figure of the **drawings** to be published with the abstract is Figure No. 4A

☐ as suggested by the applicant.

☒ as selected by this Authority, because the applicant failed to suggest a figure.

☐ as selected by this Authority, because this figure better characterizes the invention.

- b. ☐ none of the figures is to be published with the abstract.

DETECTION METHOD AND APPARATUS METAL PARTICULATES ON SEMICONDUCTORS

The invention relates to method and apparatus for detecting surface particulate defects, and especially metal particulates, in semiconductors such as silicon. The invention in particular relates to an improved method and apparatus to characterise defects likely to have an effect on the electrical activity of such semiconductor materials, and consequently a deleterious effect on the behaviour devices fabricated therefrom.

10

Surface particles in semiconductor processing are a major cause of degradation of device performance and device yield loss. Contaminate particles can locally mask lithographic, implant or etch steps which can cause shorts or open circuit. Also such particles can degrade the gate oxide integrity, which degrade the operation of all (MOS) Metal oxide semiconductor devices. Particles, with characteristic dimensions such as a fraction of the chip's smallest features can lead to killer defects.

The critical size for a technology has historically been one half or one third of the gate length for a MOS device. As semiconductors get smaller and smaller, copper is seen as a better choice for interconnects because it is a better conductor than aluminium. The tendency of copper from interconnects to diffuse into the surrounding chip material, poisoning the silicon or other semiconductor material, has largely been overcome by modifying the deposition step to first deposit a barrier material lining the etched tracks, onto which the copper is deposited, sealed by further barrier material deposition.

However, particles generated during processing can inadvertently contaminate a wafer. As with any semiconductor-manufacturing step, control of surface particles is therefore critical. It is customary to measure particulate addition to

a wafer after a process step and also after surface cleaning. Location and quantification of particles on a wafer surface is accomplished using a laser surface scanner, which detects the scattered light from surface particles. The wafer surface is excited with a focused laser beam and reflected and scattered light is collected using a number of different detectors placed at different angles relative to the excitation direction. Surface particles scatter the light in all directions away from the specular reflection direction. The particle density is detected by scattered light pulses, as the laser is scanned across the wafer. The particle size is detected through the size dependence of the scattered light and determined using calibrated standard particle sizes.

There is a lower limit to the particle size that can be detected, because of the wafer surface roughness. The surface itself has a certain amount of scattered light and if the particle scatter falls within the surface scatter it cannot be detected. New laser scanning systems angle resolved measurements could overcome this limitation. The current international specification for particles is defined as one-half of the design technology: for a 190nm device process this would be $\geq 90\text{nm}$ particles, with a density $\leq 0.18 \text{ cm}^{-2}$.

If the particle size is smaller than the qualification specification it will not be detected during particle detection. However metal particles can be present on the wafer surface that are within the current particle specification but which after processing can diffuse into the semiconductor material and have a potentially detrimental effect on the device performance, leading to enhanced leakage and gate oxide degradation.

Laser surface scanners detect all types of particles, such as organic, non-metallic and metallic. The detection of small metallic particles (below the current detection limit) that are on the surface of the wafer or are diffused into

the wafer is becoming critical for device processes using Cu interconnects. Therefore it is important to monitor incoming wafers for metallic particles, as well as device-processed wafers. In addition monitor wafers are used to detect particles in device processes equipment such as a furnace or metal etcher, and
5 this type of wafer would need to be assessed.

It is an object of the present invention to develop a method and apparatus for detecting surface particulate defects, and especially metal particulates, in semiconductors such as silicon which mitigates some or all of the above
10 disadvantages.

It is a particular object of the invention to provide a method and apparatus for detecting such surface particulate defects at sizes below current particulate qualification specifications.
15

It is a particular object of the invention to provide a method and apparatus for characterising such surface particulate defects in a manner that relates at least to some extent to their effect on the electrical activity of the semiconductor rather than to size alone.
20

Thus, in accordance with the present invention in its first aspect a method of detecting surface particulate defects, and especially metal particulates, in semiconductors such as silicon, and in particular of characterising defects likely to have an effect on the electrical activity of such semiconductor
25 materials, comprises the steps of:

exposing the surface of the semiconductor structure in the vicinity of a surface particulate to at least one high-intensity beam of light from a suitable light source, preferably a laser, and in particular a high-intensity laser;
collecting photoluminescence produced by excitation of the semiconductor
30 structure by the light beam;

processing the collected photoluminescence to produce a result representative of the intensity of the photoluminescence response;
using the result to detect and characterise surface particulate defects, and especially metal particulates, in semiconductors such as silicon, and in particular characterise defects likely to have an effect on the electrical activity of such semiconductor materials, for example by then comparing the result with suitable reference data and for example a predetermined acceptable specification range of photoluminescence to identify unacceptable contamination levels resulting from diffusion of contaminant from particulate into semiconductor structure.

The photoluminescence technique produces a spatially resolved PL map at a resolution determined by the characteristics of the high-intensity beam of light. This can be exploited by further preferred features of the present method, but for the fundamental objective of the invention is to resolve this map to a level capable of producing a result indicating the PL intensity over the wafer area in the vicinity of a surface particulate and thus obtain useful information about the level of contamination, and consequent likely detriment to electrical activity.

Photoluminescence (PL) spectroscopy is a very sensitive technique for investigating both intrinsic and extrinsic electronic transitions at impurities in semiconductors. When silicon is excited with laser irradiation above the band-gap of the material, electron hole pairs are produced. These carriers can recombine in various different ways, some of which give rise to luminescence. The electron hole pairs can be trapped at impurities in silicon and they emit photons characteristic of this interaction, thereby giving impurity specific information in the photoluminescence spectra. The spectra are inherently indicative of the electrical activity of the semiconductor material in the vicinity of the particulates, being indicative therefore of the effect on this

electrical activity of diffusion of contaminant from the particulates into the semiconductor wafer, such as might occur during fabrication even from particulates smaller than current specification. Thus, in accordance with the method a result related to the deleterious changes to electrical activity in the region of a particulate is obtained, allowing direct detection of such problems rather than indirect screening relying on particulate size considerations.

This photoluminescence result can then be used to characterise the defect and/or the likely detrimental effect on electrical activity by making a comparison of the result with previously obtained results, for example from a semiconductor sample with known defects and/ or known sample performance. For example the photoluminescence result can then be compared to a predetermined acceptable specification range developed in association with studies using more precise analysis methods (e.g. electrical yield test methods on the fabricated device). In a refinement of the method, a final step comprises making a quality classification of the semiconductor structure based upon such a comparison, and in particular rejecting or selecting for remedial action semiconductor structures exhibiting a photoluminescence response outside the said predetermined acceptable specification range.

It has generally been accepted in order to obtain this spectral information and unambiguous chemical identification of the optical centres, measurements need to be carried out at liquid helium temperatures. It is known throughout the industry that at room temperature the PL signal is significantly weakened and very little useful spectral information can be obtained. However, International patent application WO98/11425, which describes a non-destructive technique that makes practical the detection of electrically active defects in semiconductor structures based on room temperature PL. That reference discloses a PL technique which has industrial application in that it

enables the image to be produced within minutes and which has a further added advantage in producing micro imaging of small individual defects particularly near to the surface of the wafer, where the device is fabricated.

5 A room temperature PL technique is accordingly preferred, such as in particular that described by WO98/11425. Moreover, the particular effectiveness of this technique in identifying copper contamination in near-surface semiconductor structures has been described in International patent application WO02/29883. Preferred features of the methods described in
10 those applications and incorporated herein by reference will be understood to be applicable to the present invention. The present invention relies on the surprising realisation that these methods can be used not merely to detect lattice contamination inherent in the semiconductor structure for the reasons set out in those references, but is also singularly effective in detecting
15 contamination arising from diffusion of contaminant from surface particulates into the semiconductor structure, and is accordingly singularly effective in providing information about the effect of such particulates in practice which is more relevant to ultimate device performance than direct particulate measurement methods such as those based on particulate size alone.

20

The success of the room temperature PL method disclosed in the above references is, in part, due to the probing volume probed by the laser being small, spatial resolution preferably 0.1 to 20 μ m, ideally 2 to 5 μ m, and with a peak or average power density of between 10^4 to 10^9 watts/cm², so that
25 localised contaminants have much greater effect on the measured PL intensity and is also believed, in part, because since the excitation is focused the injected carrier density is high.

The light beam used to generate the PL effect is so controlled, and in
30 particular beam power and/or wavelength and/or spot size so controlled, as to

identify defects at a selective depth in said semiconductor structure, so as to collect PL information from a suitable near-surface depth reflecting the level at which the device is fabricated. Typically this might for example be from the upper 12 μ m of the semiconductor structure. For certain materials and devices, smaller depths may be appropriate, down to for example 5 μ m or even 1 μ m. In particular the light beam used to generate the PL effect is a high-intensity laser.

Reference herein to a high-intensity laser is meant to include, without limitation, a high power density laser i.e. where regardless of the power of the laser the emittance is focused.

In order to perform the method of the invention effectively, it is necessary to locate particulates posing a potential problem and then to obtain the PL information characteristic of electrical activity of contamination in the vicinity thereof, to give an indication of whether diffusion from the particulate into the surface is a problem. In a preferred embodiment therefore the method comprises a first step of locating surface particulates using a suitable particulate imaging method, and a subsequent or simultaneous second step of generating PL intensity information as above described from the vicinity of each particulate to provide a quantification of the extent to which contaminant has diffused from the particulate into the near-surface region of the semiconductor, in particular to an extent where the level of contaminant will be detrimental to device performance.

25

The basic PL technique can be used to generate a PL map imaging the PL response across the whole wafer. This is not likely to be the most rapid alternative in practice. The particulate imaging, mapping and locating method might conveniently alternatively be by another suitable method. This might

involve the generation of a scattered light dark field image and/or a reflected light bright field image.

In the former case the method might for example be a conventional laser surface scanning method as above described or another suitable relatively rapid scanning method. In the latter case the method comprises generation of a reflected light surface map of the area under test, preferably simultaneously with the PL image and using the same light source.

- 10 That is, the method includes the steps of:
- directing a high intensity beam of light such as a high-intensity laser at a surface of a sample of semiconductor structure to be tested in the manner above described;
 - producing a first or photoluminescence image from photoluminescence produced by excitation of the semiconductor structure by the light beam;
 - 15 producing a second image mapping the location of the particulates, either as a dark field image of light scattered from the surface of the semiconductor structure or as a bright field image of light reflected from the surface of the semiconductor structure;
 - 20 using the second image to detect and map surface particulates;
 - processing the photoluminescence image to produce a result representative of the intensity of the photoluminescence response of the semiconductor structure in the vicinity of the surface particulates so detected;
 - for example then comparing the result with a predetermined acceptable specification range of photoluminescence.
 - 25

The second image may be produced from light from the same primary light source as that generating the PL image, or from an additional high intensity light source, in which latter case the additional light source is preferably a laser source, such as a conventional laser scanner, and the method comprises

30

directing a second high intensity beam of light such as a high-intensity laser at a surface of a sample of semiconductor structure to be tested simultaneously or successively with the first high intensity beam of light, respectively to generate the said particulate map image and the said PL response.

5

Comparison of the first and second images to identify target particulates may be merely by simultaneous observation. Preferably however the images are analysed statistically, for example by digitizing prior to performing a numerical comparison/ analysis.

10

Preferably, the method involved generating a digitized intensity measurement (e.g. point by point reading but preferably a digitized intensity map) representative of the intensity of the first, PL image; generating a digitized intensity measurement (e.g. point by point reading but preferably a intensity digitized map) representative of the intensity of the second image; numerically processing the digitized intensity measurements to produce the result above.

15

A suitable detailed example of such a method is described in International Application No WO 02/077621.

20

The PL image and the corresponding reflected surface image or other map which is equivalent to an optical microscope image may be recorded. Surface particles are detected in reflected image. Only after contaminant from the surface particle has diffused into the wafer (and the contamination is now in the Si or other semiconductor crystal lattice) are metal-related defects produced which are electrically active. These metal related defects are now observed in the PL map because they are electrically active. Therefore it is easy to identify areas for investigation by inspecting and comparing the PL and surface image recorded at the same location.

25

30

The preferred PL technique of the present invention is capable of generating a spatially resolved PL map across the area of the wafer. In the primary method of the invention, PL intensity data is collected for each particulate which is compared with reference data to make the quality control decision. If the method is to be used for such a go-no go quality control decision then only the PL level associated with a particulate is of concern. Coarse scanning by another more rapid method to locate particulates is used as above.

Nevertheless, it is a particular advantage of the technique of the present invention that it can additionally be used to generate a spatially resolved map of PL signals across the surface of the semiconductor under test, and in particular to generate a spatially resolved image of those signals. Accordingly, in a preferred embodiment, the method further comprises the step of generating such a map and/or such an image. In these circumstances, it can be appropriate to work to mapping/imaging resolutions of 0.5 mm or less across the entire wafer. It might for example be appropriate to use such more detailed map generation on a batch sampling basis.

If the wafer is annealed this would diffuse contaminant from the particle into the wafer and make their detection easier. Accordingly, in a preferred embodiment of the method, the semiconductor material is first heated to anneal and effect such diffusion prior to carrying out the detection steps as above. This might again be more suited to a batch testing process for quality control.

25

Heating of the semiconductor material may be effected by any suitable process, for example by incorporating heating means into any carrier apparatus. Heating to temperatures of between 200 and 400°C can be suitable to encourage more rapid diffusion of target species and create the desired

annealing effect. Alternatively, the annealing effect might be produced inherently, particularly during device processing, for species with high diffusion rates at lower temperature.

- 5 Copper in particular diffuses very rapidly at low temperatures, as compared to other metallic impurities. Therefore if wafer was heated prior to analysis, the main effect observed should due especially to Cu. The method is in particular a method of detecting contamination from copper surface particulates, and in this example of the method the optional heating step is particularly useful.

10

- The result from the annealed sample may again be used to detect and characterise surface particulate defects, and especially metal particulates, in semiconductors such as silicon, and in particular characterise defects likely to have an effect on the electrical activity of such semiconductor materials, for example by then comparing the result with a predetermined acceptable specification range of photoluminescence to identify unacceptable contamination levels resulting from diffusion of contaminant from particulate into semiconductor structure.

- 20 Moreover, diffusion rates vary between species. This allows a further refinement of the invention. The detection steps may be repeated and a photoluminescence result collected prior to and subsequent to an annealing step and the results compared to determine the difference and obtain an indication of rates of diffusion so as to identify the contaminant.

25

- In a further alternative the invention thus comprises a first step of collecting photoluminescence produced by excitation of the semiconductor structure by the light beam and processing the collected photoluminescence to produce a first photoluminescence result representative of the intensity of the photoluminescence response as above described;
- 30

a heating step as above described to anneal the sample;
a second step of collecting photoluminescence produced by excitation of the semiconductor structure by the light beam and processing the collected photoluminescence to produce a second photoluminescence result
5 representative of the intensity of the photoluminescence response as above described after annealing;
a step of comparing the results of each photoluminescence step to determine the difference and obtain an indication of rates of diffusion so as to identify the contaminant.

10

Again, the comparison between first and second photoluminescence results is preferably performed numerically, for example by digitizing photoluminescence information collected at each stage prior to performing a numerical comparison/ analysis with reference to known diffusion data for
15 likely contaminant species.

In accordance with a further aspect of the invention an apparatus for detecting surface particulate defects, and especially metal particulates, in semiconductors such as silicon, and in particular for characterising defects
20 likely to have an effect on the electrical activity of such semiconductor materials, comprises means to perform the foregoing method.

In a particular example the apparatus therefore comprises a support for a semiconductor sample under test; a high intensity light source, preferably a
25 laser, and in particular a high-intensity laser; means to focus a high intensity beam of light from the light source onto a surface of a semiconductor sample under test on the support; collection means to collect photoluminescence data produced by excitation of the semiconductor structure by the light beam at least in the vicinity of particulates on the surface thereof; means to process the
30 collected data to produce a result representative of the intensity of the

photoluminescence response in the said vicinity; preferably also a comparator to compare the result with suitable reference data and for example a predetermined acceptable specification range of photoluminescence to identify unacceptable contamination levels resulting from diffusion of contaminant
5 from particulate into semiconductor structure.

Preferably the apparatus further includes means to locate particulates on the surface of the semiconductor structure, and in particular imaging means to create an image map of such location, simultaneously with the PL signal or
10 otherwise. This might be a scattered light dark field image and/or a reflected light bright field image.

In the former case the imaging means might for example be a conventional laser surface scanner as above described with suitable collection optics or
15 another suitable relatively rapid scanning method. In the latter case imaging means are provided to enable the creation of a reflected light surface map of the area under test, preferably simultaneously with the PL image using the same light source.

20 For example the apparatus includes a first imaging means to produce a first image from photoluminescence produced by excitation of the semiconductor structure by the light beam; a second imaging means to produce a second image of the surface of the semiconductor structure mapping particulates thereon, either as a dark field image of light scattered from the surface of the
25 semiconductor structure or as a bright field image of light reflected from the surface of the semiconductor structure; an image processor to process the second image to detect and map surface particulates and to process the first image to produce a result representative of the intensity of the photoluminescence response of the semiconductor structure in the vicinity of

the surface particulates so detected; and a comparator to compare the result with a predetermined acceptable specification range of photoluminescence.

5 The second image may be produced from light from the same primary light source as that generating the PL effect, or from an additional light source, in which latter case the additional light source is preferably a laser source, such as a conventional laser scanner.

10 The imaging means may include a display (direct screen, photographic, camera and screen etc) allowing simultaneous viewing by an observer. Additionally or alternatively, digital imagers such as digital cameras collect digitised image intensity data to be processed numerically as above described.

15 In further preferred embodiment of the invention the light source of the apparatus comprises a laser of a spot size of between 0.1mm and 0.5 microns and/or a power density of between 10^4 to 10^9 watts/cm².

20 Preferably the apparatus further includes means to heat the sample under test to produce the annealing effect above described. In one alternative therefore, the apparatus is an apparatus for detecting surface particulate defects, and especially metal particulates, in semiconductors such as silicon, to characterise defects likely to have an effect on the electrical activity of such semiconductor materials, and comprises a support for a semiconductor sample under test; a high intensity light source; means to focus a high intensity beam of light from
25 the light source onto a surface of a semiconductor sample under test on the support; collection means to collect photoluminescence data produced by excitation of the semiconductor structure by the light beam at least in the vicinity of particulates on the surface thereof; means to process the collected data to produce a result representative of the intensity of the
30 photoluminescence response in the said vicinity; heating means to heat the

sample in situ, allowing a photoluminescence response to be measured before and after heating, and a comparator to compare the said two photoluminescence responses to determine the difference and obtain an indication of rates of diffusion so as to identify the contaminant.

5

In particular heating means are associated with the support. For example the support comprises a heated stage.

Other preferred apparatus features will be appreciated by analogy with the foregoing description of the method.

10

The invention is illustrated with reference to Figures 1 to 5 of the accompanying drawings in which:

Figures 1 to 4 show various images produced by an apparatus in accordance with the invention;

15

Figure 5 is a schematic representation of an implementation of the invention.

Figure 1a shows a PL image revealing an area containing of surface metal particle induced contamination. After low temperature heating at 250°C (See Figure 1b) the defect contrast and the size of the area effected by the contamination have increased. The similar type of effect is shown in Figures 2a-2b. This is attributed to diffusion of the metal particle into the Si wafer.

20

Copper can diffuse into a Si wafer a room temperature, and it can diffuse through the wafer thickness (≈ 625 μm) from the wafer backside to the wafer front in 4 hours. Clearly any contamination on the backside caused by

25

handling could be transferred to the wafer front surface and effect the devices fabricated in this region.

As noted, copper diffuses very rapidly at relatively low temperatures, as
5 compared to other metallic impurities. Therefore if the wafer was heated prior to analysis in accordance with the invention, the main effect observed should be especially to Cu. Also when low levels of Cu are diffused into the crystal lattice this can cause an increase in the local PL signal (previous SiPHER Cu patent) and can be used to identify Cu metallic particles diffused into the
10 wafer.

The effect of the intentional Cu particle induced contamination was also investigated. The wafers were annealed at 400°C for 30 minutes to increase the diffusion of the metal contamination into the wafer, enhancing the
15 defective area contrast. Figure 3a-3b show large area scans revealing the contamination effect by the surface particles. These defects are shown as having halo effects or moon like features (see defects labelled P in Figures 3a-3b). These particles induced defective areas cover between 200-600 μm . The wafer could then mapped to produce a wafer map. The particle enhanced
20 diffused areas could be readily identified.

A micro scan recorded at high resolution (as shown in figure 4a-4b) reveals the effect of particle diffusion into the wafer. The PL micro map and the corresponding surface image reveal the particle in the centre of the scanned
25 area.

By measuring the image after controlled heating it would be possible to get information on the nature of the metal diffusing. Since each metal has a well known diffusion constant in Si, by heating the wafer for a fixed time and

temperature and measuring the SiPHER image before and after heating an indication of the potential type of metal contamination can be obtained.

$$L = \sqrt{4tD}$$

5

D=Diffusion coefficient at heating temperature (cm²/s)

L= Diffusion length (cm)

T=Time (Seconds)

- 10 For example heating at a temperature of 1050°C, for 1hour. Cu can diffuse up to 12mm, compared to 2mm for Fe and about 0.007 mm for Ti.

Metal particle defects could be detected by using different heating methods and chemical treatments used in a typical device process, such as furnace
15 oxidation, rapid thermal processing (RTP). Also an in-situ hot wafer chuck, or halogen lamp could be used. Alternatively laser heating could be used, either employing the light source used for the PL effect and/ or particulate imaging as above described, or from a yet further dedicated source. These could all be part of the system.

20

Also the particles could be detected using a laser surface scanner as part of the hardware. The particles could be inspected directly in the same hardware configuration using the measurement optics described for example in the prior art patent applications referred to hereinabove.

25

Also wafer maps can be recorded on the wafer backside. This helps to identify whether the source of the contamination came from the wafer back surface.

Figure 5 is a measurement process flowchart illustrating a possible implementation of the invention.

CLAIMS

1. A method of detecting surface particulate defects, and especially metal
5 particulates, in semiconductors such as silicon, to characterise defects likely to
have an effect on the electrical activity of such semiconductor materials,
comprises the steps of:
exposing the surface of the semiconductor structure in the vicinity of a surface
particulate to at least one high-intensity beam of light from a suitable light
10 source;
collecting photoluminescence produced by excitation of the semiconductor
structure by the light beam;
processing the collected photoluminescence to produce a result representative
of the intensity of the photoluminescence response;
15 comparing the result with a predetermined acceptable specification range of
photoluminescence to identify unacceptable contamination levels resulting
from diffusion of contaminant from particulate into semiconductor structure.
2. A method in accordance with claim 1 as a method of quality control
20 comprising a further step of making a quality classification of the
semiconductor structure based upon such a comparison, and rejecting or
selecting for remedial action semiconductor structures exhibiting a
photoluminescence response outside the said predetermined acceptable
specification range.
- 25 3. A method in accordance with claim 1 or claim 2 further comprising a
prior step of determining a predetermined acceptable specification from
studies of samples of fabricated devices using electrical yield test methods.

4. A method in accordance with any preceding claim wherein the semiconductor is annealed prior to carrying out the detection steps to diffuse contaminant from the particle into the semiconductor material and make detection easier.

5

5. A method in accordance with claim 4 wherein the detection steps are repeated prior to and subsequent to an annealing step and the results compared to determine the difference and obtain an indication of rates of diffusion so as to identify the contaminant.

10

6. A method of detecting surface particulate defects, and especially metal particulates, in semiconductors such as silicon, to characterise defects likely to have an effect on the electrical activity of such semiconductor materials, comprises:

15 a first step of collecting photoluminescence by:

exposing the surface of the semiconductor structure in the vicinity of a surface particulate to at least one high-intensity beam of light from a suitable light source;

20 collecting photoluminescence produced by excitation of the semiconductor structure by the light beam;

processing the collected photoluminescence to produce a first photoluminescence result representative of the intensity of the photoluminescence response;

25 a heating step to the semiconductor to diffuse contaminant from the particle into the semiconductor material;

a second step of collecting photoluminescence produced by like method to the first to produce a second photoluminescence result representative of the intensity of the photoluminescence response as above described after annealing;

a step of comparing the results of each photoluminescence step to determine the difference and obtain an indication of rates of diffusion so as to identify the contaminant.

5 7. A method in accordance with any preceding claim wherein the light source is a high-intensity laser.

8. A method in accordance with claim 7 wherein the spatial resolution of the laser is 0.1 to 20 μm .

10

9. A method in accordance with claim 7 or 8 wherein the laser provides a peak or average power density of between 10^4 to 10^9 watts/cm².

10. A method in accordance with any preceding claim wherein the light
15 beam used to generate the PL effect is so controlled as to collect PL information from no deeper than the upper 12 μm of the semiconductor structure.

11. A method in accordance with any preceding claim comprising a first
20 step of locating surface particulates using a suitable particulate imaging method, and a subsequent or simultaneous second step of generating PL intensity information in accordance with any preceding claim from the vicinity of each particulate to provide a quantification of the extent to which contaminant has diffused from the particulate into the near-surface region of
25 the semiconductor.

12. A method in accordance with claim 11 wherein the particulate imaging, mapping and locating method comprises the generation of a scattered light dark field image and/or a reflected light bright field image.

30

13. A method in accordance with claim 12 including the steps of:
directing a high intensity beam of light such as a high-intensity laser at a surface of a sample of semiconductor structure to be tested in the manner above described;
- 5 producing a first or photoluminescence image from photoluminescence produced by excitation of the semiconductor structure by the light beam;
producing a second image mapping the location of the particulates, either as a dark field image of light scattered from the surface of the semiconductor structure or as a bright field image of light reflected from the surface of the
- 10 semiconductor structure;
using the second image to detect and map surface particulates;
processing the photoluminescence image to produce a result representative of the intensity of the photoluminescence response of the semiconductor structure in the vicinity of the surface particulates so detected.
- 15
14. An apparatus for detecting surface particulate defects, and especially metal particulates, in semiconductors such as silicon, to characterise defects likely to have an effect on the electrical activity of such semiconductor materials, comprises a support for a semiconductor sample under test; a high
- 20 intensity light source; means to focus a high intensity beam of light from the light source onto a surface of a semiconductor sample under test on the support; collection means to collect photoluminescence data produced by excitation of the semiconductor structure by the light beam at least in the vicinity of particulates on the surface thereof; means to process the collected
- 25 data to produce a result representative of the intensity of the photoluminescence response in the said vicinity; a comparator to compare the result with a predetermined acceptable specification range of photoluminescence to identify unacceptable contamination levels resulting from diffusion of contaminant from particulate into semiconductor structure.

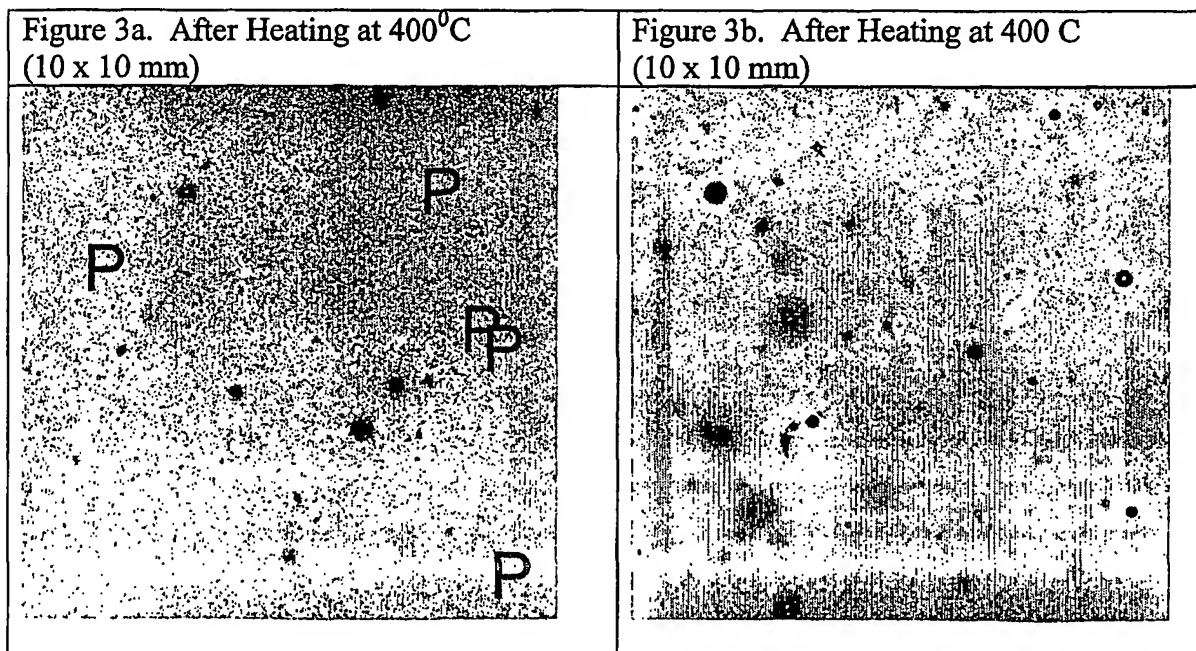
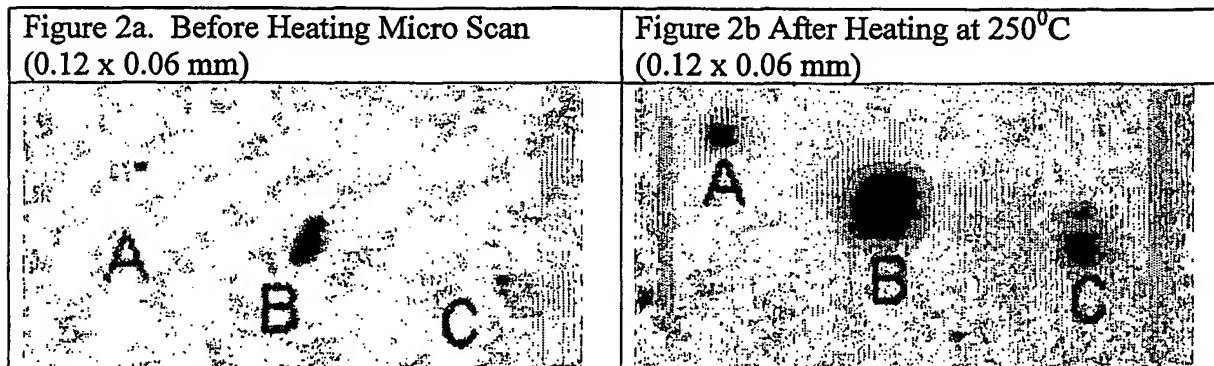
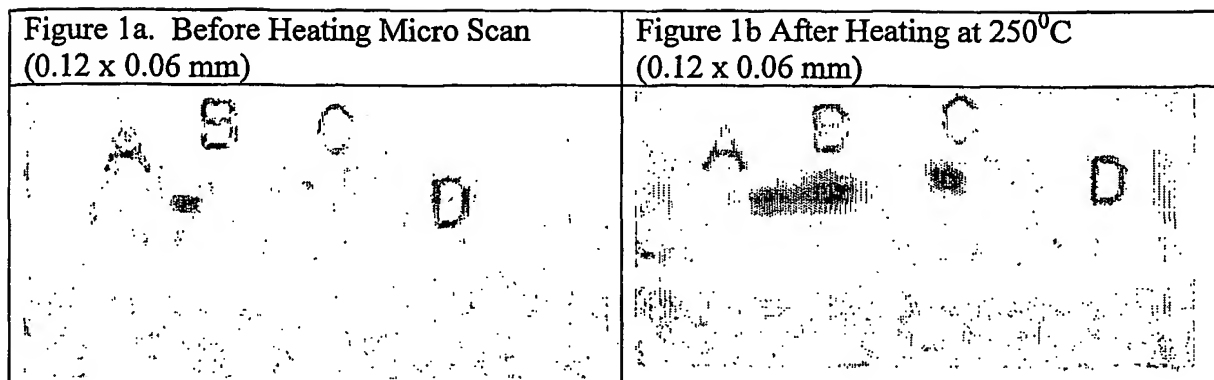
15. An apparatus in accordance with claim 14 further including means to heat the sample under test associated with the support.

16. An apparatus for detecting surface particulate defects, and especially metal particulates, in semiconductors such as silicon, to characterise defects likely to have an effect on the electrical activity of such semiconductor materials, comprises a support for a semiconductor sample under test; a high intensity light source; means to focus a high intensity beam of light from the light source onto a surface of a semiconductor sample under test on the support; collection means to collect photoluminescence data produced by excitation of the semiconductor structure by the light beam at least in the vicinity of particulates on the surface thereof; means to process the collected data to produce a result representative of the intensity of the photoluminescence response in the said vicinity; heating means to heat the sample in situ, allowing a photoluminescence response to be measured before and after heating, and a comparator to compare the said two photoluminescence responses to determine the difference and obtain an indication of rates of diffusion so as to identify the contaminant.

17. An apparatus in accordance with claim 15 or claim 16 wherein the heating means comprises a heated stage.

18. An apparatus in accordance with one of claims 15 to 17 further including imaging means to create an image map of the location of particulates on the surface of the semiconductor structure.

19. An apparatus in accordance with claim 18 wherein the imaging means generates a scattered light dark field image and/or a reflected light bright field image.



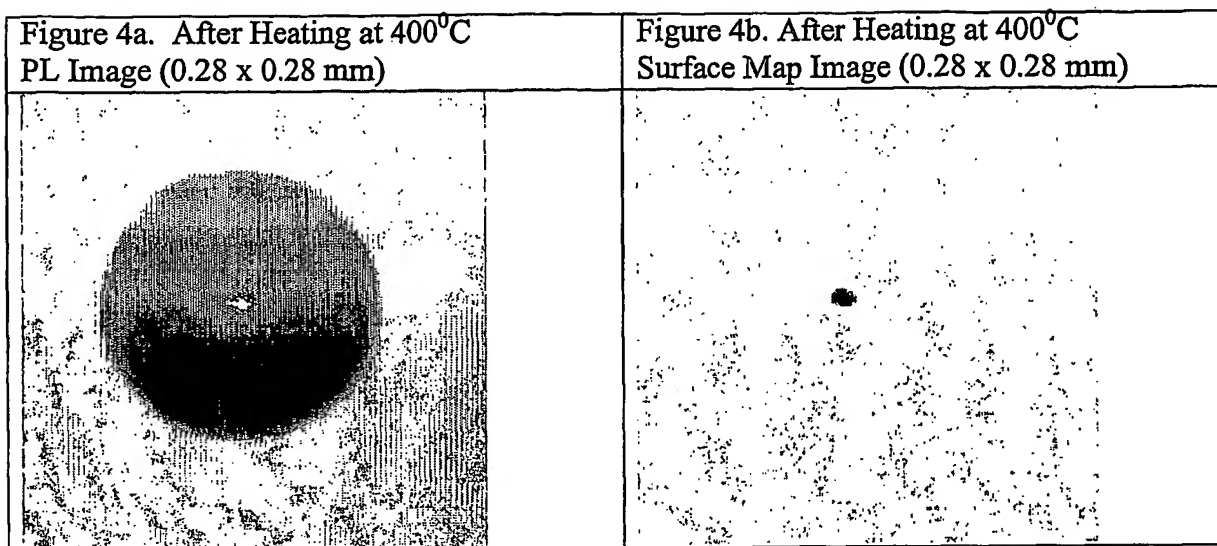
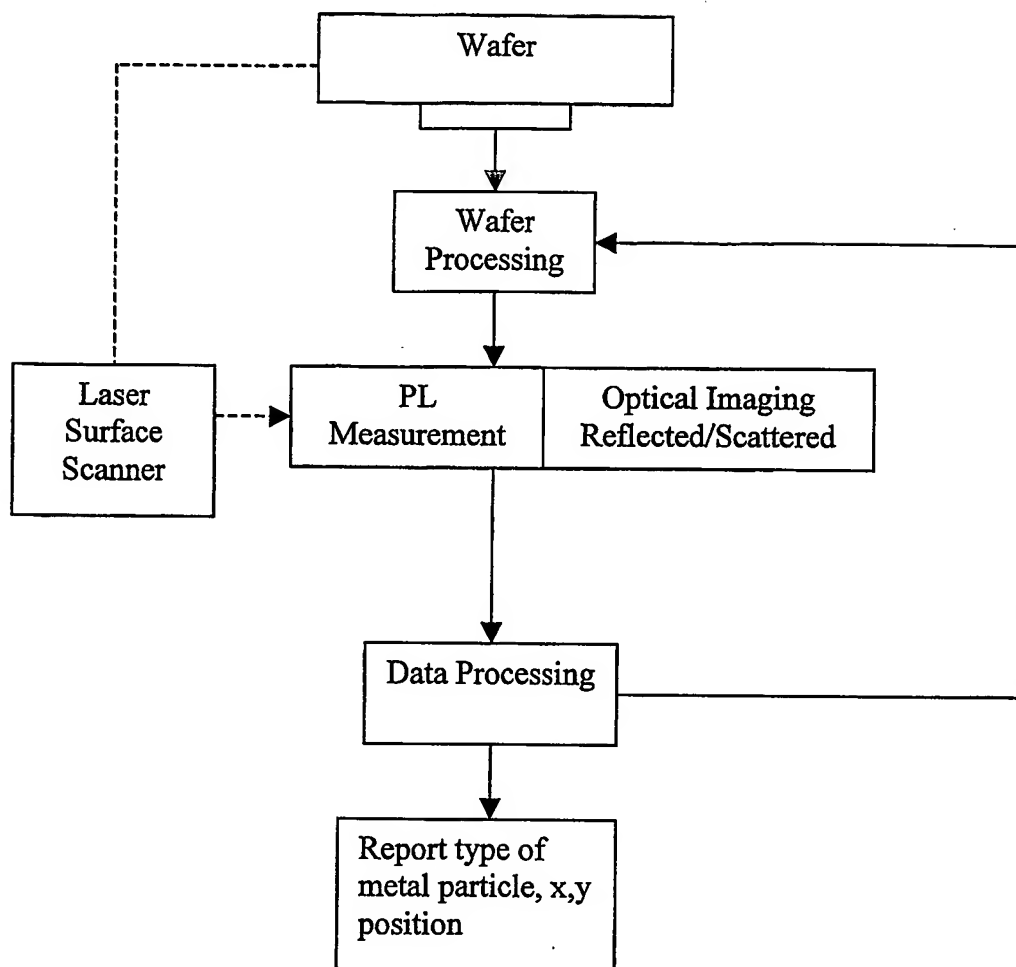


Figure 5. Measurement Process Flowchart

International Application No
PCT/GB2004/001521

page 1 of 3

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB2004/001521

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 98/11425 A (BIO RAD MICROMEASUREMENTS LTD ;MAYES IAN CHRISTOPHER (GB); HIGGS V) 19 March 1998 (1998-03-19) page 16, line 7-11 ---	1-19
A	WESTRATE S ET AL: "PHOTOLUMINESCENCE MAPPING DETECTS CU CONTAMINATION IN SI WAFERS" SOLID STATE TECHNOLOGY, COWAN PUBL.CORP. WASHINGTON, US, vol. 45, no. 2, February 2002 (2002-02), pages 57-58, XP001092608 ISSN: 0038-111X page 58, line 1,2 ---	1-19
A	HIGGS V ET AL: "Application of room temperature photoluminescence for the characterization of impurities and defects in silicon" PROCEEDINGS OF THE SPIE, SPIE, BELLINGHAM, VA, US, vol. 3895, 13 September 1999 (1999-09-13), pages 21-37, XP002187098 ISSN: 0277-786X page 24-26 ---	1-19
A	COMMERE B ET AL: "Control of the Fabrication Steps of InP MIS Transistors by Means of Scanning Photoluminescence Measurements" JOURNAL DE PHYSIQUE. COLLOQUE, PARIS, FR, vol. 49, no. C-4, SUPPL 9, September 1988 (1988-09), pages 431-436, XP009017749 ISSN: 0449-1947 page 432, line 1-27 ---	1-19
A	PATENT ABSTRACTS OF JAPAN vol. 2000, no. 10, 17 November 2000 (2000-11-17) & JP 2000 193597 A (SUMITOMO METAL IND LTD), 14 July 2000 (2000-07-14) abstract; figure 1 ---	1-19
A	PATENT ABSTRACTS OF JAPAN vol. 2000, no. 01, 31 January 2000 (2000-01-31) & JP 11 274257 A (SHIN ETSU HANDOTAI CO LTD), 8 October 1999 (1999-10-08) abstract; figure 2 --- -/-	1-19

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB2004/001521

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	PATENT ABSTRACTS OF JAPAN vol. 2000, no. 03, 30 March 2000 (2000-03-30) & JP 11 354599 A (MEMC KK), 24 December 1999 (1999-12-24) abstract; figure 4 -----	1-19
A	HIGGS V: "Characterization of Si, SiGe and SOI Structures using Photoluminescence" MATERIALS RESEARCH SOCIETY SYMPOSIUM PROCEEDINGS, MATERIALS RESEARCH SOCIETY, PITTSBURG, PA, US, vol. 588, 2000, pages 129-140, XP009017743 ISSN: 0272-9172 figures 2,12 -----	1-19

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/GB2004/001521

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
WO 0229883	A	11-04-2002	AU 9211001 A	15-04-2002
			CN 1479944 T	03-03-2004
			EP 1323188 A1	02-07-2003
			WO 0229883 A1	11-04-2002
			JP 2004511104 T	08-04-2004
			US 2004106217 A1	03-06-2004
WO 02077621	A	03-10-2002	EP 1373869 A1	02-01-2004
			WO 02077621 A1	03-10-2002
			US 2004092042 A1	13-05-2004
JP 2003045928	A	14-02-2003	NONE	
WO 9811425	A	19-03-1998	AU 4126997 A	02-04-1998
			DE 69718917 D1	13-03-2003
			DE 69718917 T2	19-02-2004
			EP 0925497 A1	30-06-1999
			WO 9811425 A1	19-03-1998
			JP 3440421 B2	25-08-2003
			JP 2001500613 T	16-01-2001
			KR 2000035954 A	26-06-2000
JP 2000193597	A	14-07-2000	NONE	
JP 11274257 7	A		NONE	
JP 11354599 7	A		NONE	